MAGNETOFOSSILS IN TERRESTRIAL SAMPLES AND MARTIAN METEORITE ALH84001

Kathie L. Thomas-Keprta
Lockheed Martin
Mail Code C-23, NASA/JSC
Houston, TX 77058
kthomas@ems.jsc.nasa.gov

Simon J. Clemett
Lockheed Martin

Dennis A. Bazylinski
Dept. of Microbiology
Iowa State University
207 Science 1
Ames, IA 50011

Joseph L. Kirschvink
Division of Geological and Planetary Sciences
California Institute of Technology
1200 E. California Blvd.
Pasadena, CA 91125

David S. McKay
NASA/JSC, Mail Code SN
Houston, TX 77058

Susan J. Wentworth
Lockheed Martin

H. Vali
Dept. of Earth and Planetary Sciences
McGill University
3450 University Street
Montreal, Quebec H3A2A7, Canada

Everett K. Gibson
NASA/JSC, Mail Code SN
Houston, TX 77058

Introduction: Here we compare magnetite crystals produced by terrestrial magnetotactic bacteria strain MV-1 with a subpopulation of magnetites from ALH84001. We find both to be chemically and physically identical -- specifically, both are single-domain, chemically pure, and exhibit an unusual crystal habit we describe as truncated hexa-octahedral [1]. On Earth such truncated hexa-octahedral magnetites are only known to be produced by magnetotactic bacteria. We suggest that the observation of truncated hexa-octahedral magnetites in ALH84001 are both consistent with, and in the absence of terrestrial inorganic analogs, likely formed by biogenic processes.

Magnetotactic bacteria strain MV-1: Six specific properties of biogenic magnetite can be identified that when met collectively, constitute a rigorous biosignature (i.e., one that is not produced by natural inorganic processes) [2]. These are: (1) narrow size-range (i.e., single-domain for uniform magnetization) and shape (restricted width-to-length (W/L) ratios); (2) chemical purity; (3) few crystallographic defects; (4) truncated hexa-octahedral morphology (Fig 1.); (5) elongation along the [111] axis; and (6) alignment in chains within cells. These properties all act to optimize the interaction of the magnetites with a magnetic field. Since the strength of magnetic field interactions are much smaller than thermal energies kT, on thermodynamic grounds alone, chemical and biological processes cannot be influenced by magnetic fields to any measurable degree [3]. Hence the six characteristics, outlined above, have *evolved* through the process of natural selection. No published reports of inorganic truncated hexa-octahedral magnetites are known.

ALH84001 Truncated Hexa-octahedral Magnetites: Approximately 25% of the Martian magnetites, found embedded in ~3.91 Ga old carbonate globules [4], display 5 of the 6 properties described previously (since our extraction procedure destroyed spatial relationships, the presence aligned magnetite chains could not be evaluated). While the Martian truncated hexa-octahedral magnetite crystals are indistinguishable from those produced intracellularly by magnetotactic bacterium strain MV-1 [1,2] (Fig. 1), they are both chemically and physically distinct from the remaining ~75% of the magnetites in ALH84001. These other magnetites appear analogous to terrestrial inorganic magnetites (intimate mixtures of both biogenic and abiotic magnetite crystals [2] are observed in terrestrial samples of both recent and ancient carbonates).

Summary and Conclusions: Truncated hexa-octahedral magnetites on Earth are exclusively the product of biogenic activity -- no natural or synthetic inorganic process is known that could explain the observation of truncated hexa-octahedral magnetites in a terrestrial sample. Unless there is an unknown and unexplained inorganic process on Mars, which is conspicuously absent on the Earth, we suggest that ALH84001 truncated hexa-octahedral magnetites formed by a mechanism similar to its terrestrial biogenic counterpart. *As such, these crystals are interpreted as Martian magnetofossils and constitute evidence of the oldest life yet found.*

References: [1] Thomas-Keprta, K.L. *et al. Proc. Nat. Acad. Sci.*, in press. [2] Thomas-Keprta, K.L. *et al.* (2000) *GCA* **64**, 4049-4081. [3] Shulten, K. (1982) *Festkorperprobleme*, **22**, 61-83. [4] Borg L.E. *et al.* (1999) *Science* **286**, 90-94

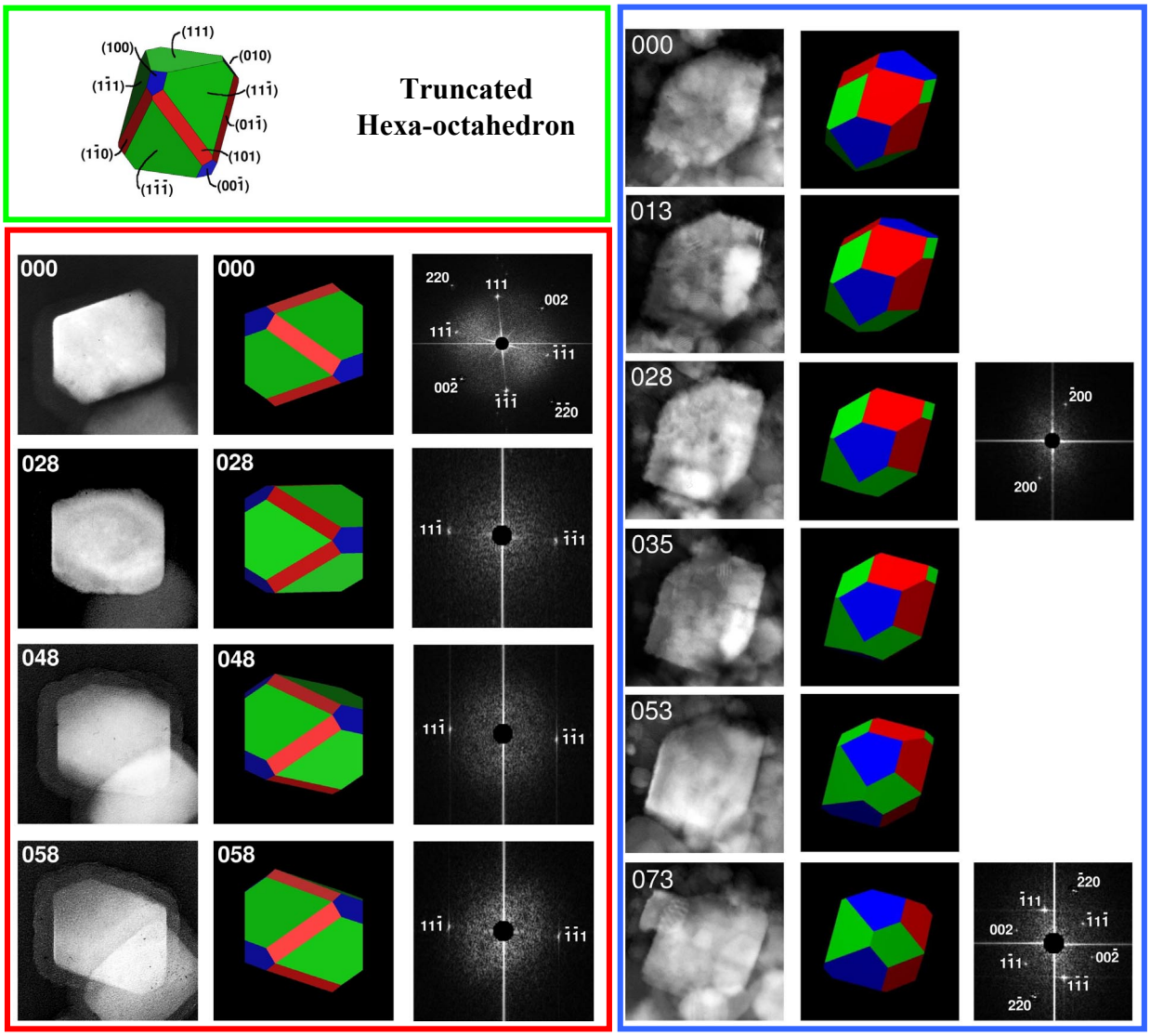

Figure 1: Idealized truncated hexa-octahedral crystal habit of magnetite (green box). A truncated hexa-octahedron is elongated along one of the [111] zone axes and displays eight {111} octahedral (green), six {110} dodecahedral (red), and six {100} cubic (blue) faces.

Example of a single truncated hexa-octahedral MV-1 magnetite examined under incremental TEM stage rotation (red box). Magnetite at 000° is viewed down the [1-10] zone axis. At 058° (~60° rotation) the same magnetite is now viewed approximately down the [-101] zone axis (mirror image of crystal at 000°). Rotation axis is perpendicular to the plane of the page and aligned vertically.

Example of a single, truncated hexa-octahedral ALH84001 magnetite, extracted from carbonate, and rotated a total of 73° (blue box). At 073°, the crystal is viewed down the [110] zone axis. Rotation axis is perpendicular to the plane of the page and inclined ~20° to the right of the vertical. Note the {100}and {110}faces are expressed to a greater degree than observed for the MV-1 magnetite example shown here.